Speckle Patterns from Antiferromagnetic Domains

S.Eisebitt[1], M. Lörgen[1], R. Scherer[1], W. Eberhardt[1],
J. Lüning[2], J. Stöhr[2], S. Tixier[3], T. Tiedje[3] A. Scholl[4]
[1]Institut für Festkörperforschung, Forschungszentrum Jülich, 52425 Jülich, Germany
[2]IBM Research Division, Almaden Research Center, 650 Harry Rd. San Jose, CA 95120, USA
[3]Advanced Material Process and Engineering Lab, Department of Physics and Astronomy,
University of British Columbia, Vancouver, BC V6T 1Z4, Canada
[4] ALS, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

INTRODUCTION

Thin magnetic films are of technological importance but are also interesting from a basic science point of view. While several techniques are available to study the domain structure of ferromagnetic materials, antiferromagnetic thin films and surfaces are difficult to study due to their magnetically compensated nature. Only recently, the first images of a surface with clear antiferromagnetic contrast have been presented, by exploiting x-ray magnetic linear dichroism (XMLD) as an absorption effect in a photoelectron emission microscope (PEEM) [1]. While such a real space imaging approach is extremely valuable, we present here a way to study antiferromagnetic surfaces and thin films in reciprocal space by coherent soft x-ray scattering. This approach will allow the study of magnetic domains in the presence of magnetic fields, which is virtually impossible with electron based techniques like PEEM. Exploiting the XMLD in reflection at the Fe L_3 edge, we have observed the speckle patterns generated by coherent scattering of linearly polarized x-rays from a $LaFeO_3$ film. While this technique does not directly provide real space information, the variation of the speckle pattern in time can be used to study the dynamics of the system beyond statistical properties, as the speckle pattern is sensitive to the individual domain configuration of the surface. For example, critical fluctuations at phase transitions could be studied. Such dynamic light scattering experiments are common in the visible region using lasers and have recently been shown to be possible for non-magnetic scattering using soft x-rays as well [2-4]. For a ferromagnetic sample, which exhibited a high degree of order, coherent soft x-ray scattering exploiting x-ray magnetic circular dichroism (XMCD) has been reported recently[5].

EXPERIMENTAL

Linearly polarized light was generated by the U5 undulator and monochromatized at beamline 8 of the ALS. Without refocussing optics, the monochromatized beam entered our home built end station and passed through a double pinhole coherence filter about 32 m downstream of the undulator (6 m downstream of the BL8 exit slit). Low energy stray light was blocked before the pinholes by a Co transmission filter. While the first pinhole (40 µm) was mainly used to reduce stray light, the second pinhole (5 µm), located 30 mm in front of the sample, selected a small part of the coherent beam which is then incident on the sample. The (glancing) angle of incidence for the data presented here was 5°. The scattering plane is vertical and perpendicular to the E-vector of the incident radiation. The scattered light was detected by a 2D position sensitive detector based on a CsI coated multi channel plate stack and a resistive anode readout with a pixel size of 20 µm in the scattering plane (y) and 40 µm in the perpendicular direction (x). The coherence of the beam was checked by recording Fraunhofer diffraction rings. The energy resolution of the monochromator was set to 0.6 eV at 710 eV, resulting in a longitudinal coherence width of 2 µm. The $LaFeO_3$ film was grown in an oxide molecular beam epitaxy system by means of a block-by-block growth method on a $SrTiO_3$ (100) substrate [6]. The substrate surface was miscut by 2° which favors the growth of $LaFeO_3$ crystallographic domains with the c-axis parallel to the surface terraces over the second possible orientation perpendicular to the terraces, i.e., the $LaFeO_3$ film has a crystallographic in-plane anisotropy. This crystallographic anisotropy translates one-to-one in an antiferromagnetic anisotropy as shown for this particular film by TEM and PEEM.

RESULTS AND DISCUSSION

The sample is mounted such that its antiferromagnetic domains are oriented parallel and perpendicular to the electric field vector of the incident x-rays. The domains show up as black and white areas in XMLD PEEM images. (XMLD PEEM images of similar $LaFeO_3$ samples are shown in the articles by A. Scholl *et al* and F. Nolting *et al* in this compendium.) The XMLD contrast occurs between two crystal field split peaks of the Fe L_3 edge in the x-ray absorption spectrum. By changing the excitation energy by 1.8 eV from one peak to the other, the absorption of one type of domains decreases while the absorption of the perpendicularly oriented domains increases. The same effect is observable in reflectivity. Due to the in-plane anisotropy of the sample, this effect is detectable even when integrating over a large sample area containing many domains in a reflectivity measurement. Reflectivity curves which have been recorded with (a) the direction of the E-vector fixed parallel to one type of domain and (b) after rotating the sample from this position by 90° around the surface normal exhibit XMLD. The speckle experiment is now performed by tuning the incident x-ray energy to the two crystal field split peaks and by comparing the resulting speckle patterns in the coherent scattering. The sample position is not changed during this procedure, so that the illuminated area on the sample remains the same. The basic idea is that for a suitable incident energy, one set of domains will scatter more strongly (higher reflectivity) than the other domains which are rotated by 90°. For this energy, the sample has a unique spatial reflectivity pattern, which in a coherent scattering experiment will translate into a unique speckle pattern. The anisotropy of the sample is not important for this effect. In Fig. 1, we present an overview image of the intensity distribution of the scattered x-rays on the detector. The largest intensity is found in vicinity of the center (x,y =450,520), corresponding to the specular direction. For better visibility of the weaker structures, we have saturated the color z scale in the image in this region. Around the center, more than ten Fraunhofer diffraction rings are visible. The rings are not perfectly circular due to internal structure in the pinhole. This reflection of the beam with its Fraunhofer structure is restricted to a certain region of the detector, located between the lines marked “b” in Fig. 1. Within this region, large structures on the sample such as specs of dust show up as a real space image on the detector as they shade the sample surface. The dark triangular structure below “c” in the image is due to this effect, as verified by moving the illuminated area of the sample. Features like this are useful as an online check of the position of the illuminated area on the sample. Above/below the lines “b”, the horizon of the sample cuts off the specular reflection. Diffuse

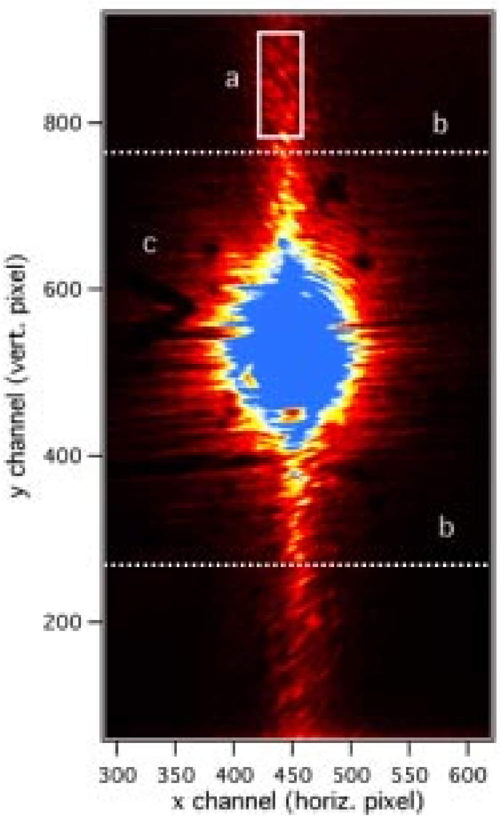

Figure 1. Overview of the 2D intensity distribution of the scattered soft x-rays. The linear z false color scale has been purposely saturated in the center. The field of view shown corresponds to the range [$-3.5\mu m^{-1}$, $3.4\mu m^{-1}$] of momentum transfer in the scattering plane and [$-33.7\mu m^{-1}$, $35.9\mu m^{-1}$] perpendicular to the scattering plane.

scattering, however, can reach these regions, which are therefore useful to observe the speckle patterns in the diffusely scattered radiation without superposition of the Fraunhofer pattern. The diffuse scattering is clearly visible in Fig. 1 as an elongated band in the scattering plane. Speckles are visible in most parts of the image.

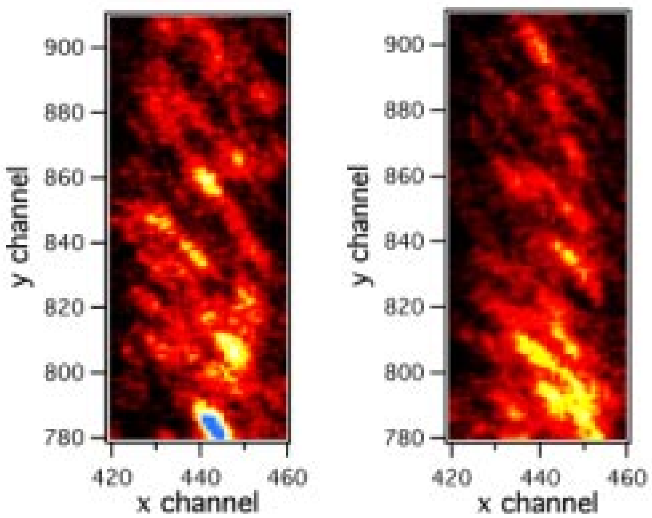

Figure 2. The speckle patterns in region "a" of Fig. 1 for an incident x-ray energy of 708.2 eV (left) and 710.0 eV (right), corresponding to the two Fe L_3 reflectivity peaks in $LaFeO_3$ exhibiting XMLD.

The main result from our preliminary data analysis is that the speckle patterns change, when the excitation energy is changed from one reflectivity peak to the other, indicating antiferromagnetic contrast. Two patterns from region "a" obtained by exclusively changing the incident x-ray energy from one reflectivity peak to the other are presented in Fig. 2. The patterns are reproducible, when the excitation energy is changed back to its previous value. This visual impression is supported by calculating correlations between the images, which show significantly lower correlation for images recorded on different reflectivity peaks than for images recorded on the same peak. While in addition to magnetic scattering surface topology scattering can also be expected to contribute to the total scattering, it will not produce changing speckle patterns when the incident energy is changed by only 0.25%, as is case for our speckle experiments. We have experimentally verified this expectation by changing the incident energy by the same relative amount at energies below the Fe L_3 edge. In this case, we observe no significant changes in the speckle pattern. We would like to point out that the envelope of the scattered intensity contains the same statistical domain size information as in an incoherent scattering experiment [7] so that a speckle experiment can be used to probe dynamics on a length scale determined by the momentum transfer. To our knowledge, this is the first experimental observation of x-ray speckle patterns generated by antiferromagnetic domains.

ACKNOWLEDGMENTS

We would like to thank J. Bozek, B. Rude , and the ALS electronics and vacuum groups for their excellent support.

REFERENCES

1. J. Stöhr, *et al.*, Phys. Rev. Lett **83**, 1862 (1999)
2. A.C. Prize *et al.,* Phys. Rev. Lett. 82, 755 (1999)
3. S.Eisebitt *et al.*, Synchrotron Radiation News **11** No.5, 15 (1998)
4. M. Adamcyk *et al.,* JVST B, **17**, 1728 (1999)
5. H.A. Dürr *et al.,* Science **284**, 2166 (1999)
6. J.-P. Locquet *et al.*, Nature **394**, 453 (1998)
7. J.F. MacKay *et al*., Phys. Rev. Lett. **77**, 3925 (1996); S.K. Sinha *et al.*, , Phys. Rev. B **38**, 2297 (1988)

This work was supported by the BMBF, WTZ-KAN027/98MPT

Principal investigator: Stefan Eisebitt, Institut für Festkörperforschung, Fortschungszentrum Jülich.
Email: s.eisebitt@fz-juelich.de. Telephone: +49-2461-61-4248, Fax. +49-2461-61-4248.